EXPERIMENTAL STUDY ON THE THERMAL PERFORMANCE OF AN AIR CONDITIONING SYSTEM IN A PURE ELECTRIC VEHICLE

by

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This paper studies the thermal performance of an air conditioning system in a pure electric vehicle. An experiment is designed to examine the main factors affecting the performance, and the experimental results show that a heat pump with a low pressure gas-mixing system can increase the heating capacity and decrease the discharge temperature.

Key words: *thermal performance, pure electric vehicles, air conditioning system, superheat*

Introduction

With the rapid development of industry, some accompanied problems, such as energy shortage and environmental pollution, have seriously restricted the sustainable development of mankind. People have begun to seek new energy vehicles to replace traditional ones due to growing pressure from socio-economics and environmental request. Among all new energy vehicles, pure electric vehicles will become the most promising one to replace traditional ones in the 21st century with their features of energy-saving and efficiency in service. For an air conditioning system in a pure electric vehicle, the use of the *single cooling system + electric heating* technology will severely restrict their application range and damage their market competitiveness [1-4]. However, heat pump air conditioning technology is clean, non-polluting, efficient, and energy-saving, laying a foundation for the application and promotion of the air conditioning system. Antonijevic *et al.* [5] established a heat pump air conditioning system in 2004, which was tested at low temperatures, and the test results were compared with the performance of an electric heating system. Yokoyama *et al*. [6] analyzed the energy consumption of electric vehicles. Steiner *et al*. [7] designed the CO_2 heat pump air conditioning system for electric vehicles, and conducted a systematic analysis and research on the defrosting process of air conditioning. Li *et al*. [8] designed a set of vapour-compression-type heating and cooling dual-mode air conditioning systems. Kowsky *et al*. [9] designed a heat pump air conditioning system to achieve refrigeration and heating without reversible changes in the refrigerant flow direction. Peng *et al*. [10] used a steady-state concentration parameter

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model, through the Simulink software to study an electric vehicle heat pump air conditioning system. Yan *et al*. [11] controlled the evaporator outlet superheat through a new kind of electronic expansion valves, and discovered that the evaporator capacity increased along with the decrease of evaporator outlet superheat. For electric vehicle heat pump air conditioning systems, energy saving, high efficiency and security have gradually become the focus of major automobile manufacturers in the choice of new energy vehicle configurations, but the structure is complex, low temperature performance is poor, so we also need to solve these problems [12-17]. At present, many researchers have conducted in-depth research on the thermal performance of automotive air conditioning systems, however, there are few reports on the air conditioning system performance of heat pump pure electric vehicles with low pressure gas-mixing systems by the evaporator outlet superheat changes.

This paper builds a test bench for a heat pump-type pure electric vehicle air conditioning system with low pressure refrigerant gas to test the effects of different evaporator outlets. The influence of heat on parameters such as system heat exchange capacity, EER, COP, compressor exhaust temperature, and air supply temperature in the car is studied. The purpose of this paper is to find the optimal evaporator outlet superheat value and to study the variable operating conditions of the compressor's low pressure make-up refrigerant gas.

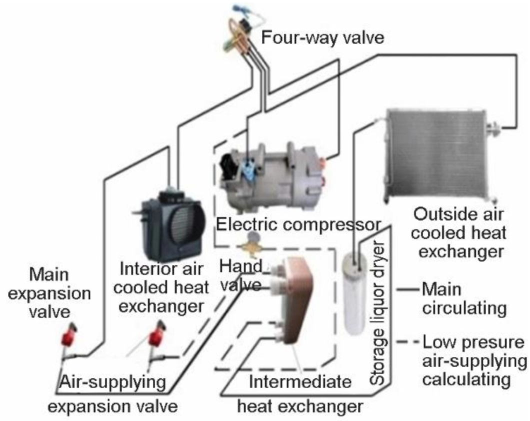

Figure 1. Heat pump pure electric vehicle air conditioning system diagram

Figure 2. Test bench of heat pump pure electric vehicle air conditioning system

Test device and test conditions

The air conditioning system of a heat pump pure electric vehicle with low pressure gas-mixing efficiency technologies and the test bench of the air conditioning system for the heat pump pure electric vehicle are shown in figs. 1 and 2, respectively:

– *Cooling mode operation test process:* high temperature and high pressure gaseous refrigerant is discharged to the electric vortex-type compressor → four-way valve → exterior air-cooled heat exchanger → drier → intermediate heat exchanger, and then it was divided into two streams: one flows through the system's main road expansion valve to interior air-cooled heat exchanger → four-way valve → compressor; the other runs through the system's side auxiliary road expansion valve → intermediate heat exchanger, to achieve the system's main road refrigerant supercooling and compressor refrigerant gas-mixing under low pressure conditions.

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The test was carried out in a constant temperature and constant humidity laboratory in Zhongyuan University of Technology of China. The R134a was selected as the system refrigerant, with the main items of equipment listed in tab. 1. Test conditions were given as: the indoor ambient dry bulb temperature was 10-40 °C, the wet bulb temperature was 9-35 °C and the outdoor environment dry bulb temperature was –20 °C to 55 °C, the wet bulb temperature was –21 °C to 45 °C, and the temperatures were controlled to within ±0.2 °C.

Table 1. Main items of equipment

Equipment name	Device parameters	Unit	Quantity
Electric vortex type compressor	EVS34C Denso Corporation EVS34C	Set	1
Interior heat exchanger	Stacked heat exchanger	Set	1
Exterior heat exchanger	Parallel flow heat exchangers	Set	1
Intermediate heat exchanger	Plate heat exchanger	Set	1
Main road electric expansion valve	E2V-09	Piece	1
Auxiliary road electric expansion valve	E2V-05	Piece	1

Test procedures and data analysis

Testing was conducted under standard cooling conditions, the dry bulb temperature of the vehicle exterior inlet air was 35 °C, the wet bulb temperature was 24 °C, the dry bulb temperature of the vehicle interior inlet air was 27 °C, and the wet bulb temperature was 19.5 °C. The exterior heat exchanger surface wind speed was 4.5 m/s, the interior fan voltage was 6 V, the compressor was set to 2000 rpm, and the debugger evaporator outlet superheats were separately 3, 5, and 7 K. The cooling performance of the air conditioning system was tested as shown in fig. 3.

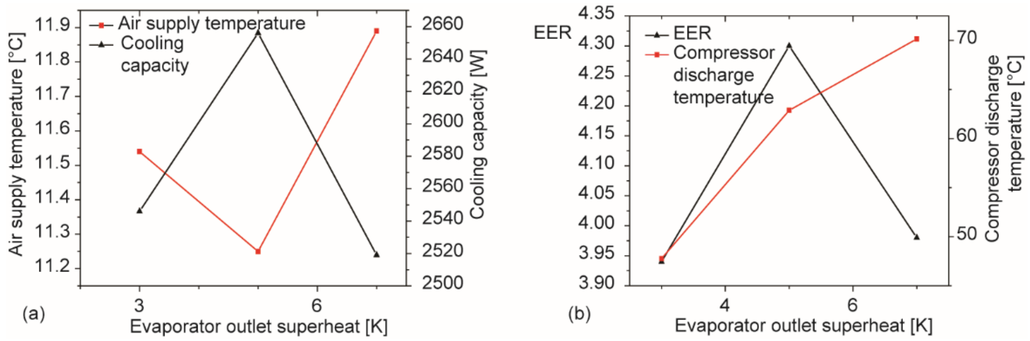

Figure 3. Influence of evaporator outlet superheat on cooling system performance; (a) air supply temperature, cooling capacity changes and (b) EER, compressor discharge temperature changes

The evaporator outlet superheat raised from 3 K to 5 K, the interior air supply temperature decreased, and the cooling capacity increased by 4.13%, EER increased by 8.33%, the discharge temperature also increased to some extent. When the evaporator outlet superheat raised from 5 K to 7 K, the interior air supply temperature increased, and cooling capacity decreased by 5.17%, EER dropped to 3.97, the discharge temperature was raised to 70.2 °C. The expansion valve was only slightly open when the evaporator outlet superheat was 7 K. The study showed that when the evaporator outlet superheat was set to 5 K, the interior air supply temperature was relatively low, the cooling capacity increased by up to 5.17%, and the EER increased by up to 8.33%, which was the best superheat value of the evaporator outlet of the air conditioning system of this electric vehicle.

We turned off the system auxiliary road expansion valve, and conducted heating test under the conditions of interior return air at 20 °C, an external environment of –7 °C, a compressor rate of rotation of 5000 rpm, with the evaporator superheat set to 5, 10, 15, and 20 K, respectively, to analyze its impact on common heat pump heating system performance. The influence of evaporator outlet superheat on common heat pump heating system performance was shown in fig. 4.

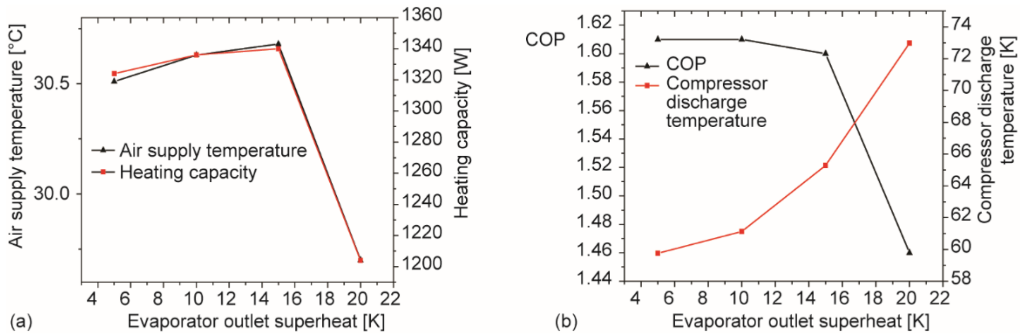

Figure 4. Influence of evaporator outlet superheat performance; (a) changes in air supply temperature and heating capacity and (b) COP, compressor discharge temperature changes

According to fig. 4, with the increase of evaporator outlet superheat, the compressor discharge temperature gradually increased. When the evaporator outlet superheat increased from 5 K to 15 K, the interior air supply temperature increased to 30.7 °C, the heating capacity increased by 1.21% with small increase range and COP remained unchanged, the compressor discharge temperature showed an increasing trend. When the evaporator outlet superheat was raised to 20 K, the heating capacity decreased by 9.83%, COP decreased by 8.73%, and the compressor discharge temperature increased to 72.9 °C. The study showed that, when evaporator outlet superheat was set to 15 K, the system heating capacity can be enhanced by up to 9.83%, the COP remained unchanged, and the system performance was optimal.

This research was conducted using a low pressure refrigerant gas, the influence of compressor discharge superheat and evaporator outlet superheat on mixed gas type heat pump heating performance was shown in fig. 5.

As seen from fig. 5, when the compressor discharge superheat increased from 15 K to 20 K, the interior air supply temperature reduced significantly, the heating capacity decreased slightly, while COP and compressor discharge temperature increased slightly. When the compressor discharge superheat increased from 20 K to 25 K, the interior air supply tem-

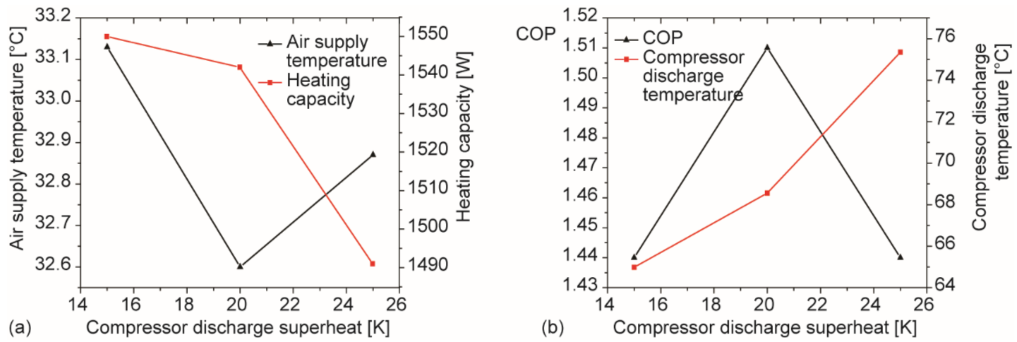

Figure 5. Influence of compressor discharge superheat and evaporator outlet superheat; (a) changes in air supply temperature and heating capacity and (b) COP and compressor discharge temperature changes

perature increased slightly, the heat exchange volume was reduced by 3.28%, COP decreased to 1.42, and the compressor discharge temperature increased by 9.81%. This was because, when the compressor discharge superheat was set to some small value, the auxiliary road expansion valve opened to a wider position, and the compressor's volume also increased correspondingly, as a result, a significant enthalpy increase was predicted. The results showed that: when the evaporator outlet superheat and compressor discharge superheat were set to 5 K and 20 K, respectively, the system heating capacity increased by 3.28% at most, and the compressor's discharge temperature decreased by 9.81% at most. Refrigerant gas-mixing systems, under low pressure, offered the optimal system performance.

The studied mixed gas type heat pump air conditioning system with low pressure and traditional PTC heating air conditioning system's heating effect are shown in figs. 6-8 for the external environment temperatures of –15 °C, –10 °C, –5 °C, and 0 °C, respectively, and the interior environment temperature of 20 °C. The main and side expansion valve superheats were 5 K and 20 K, respectively, the compressor's rate of rotation was 5000 rpm, and the interior blower capacity was 390 m^3/h.

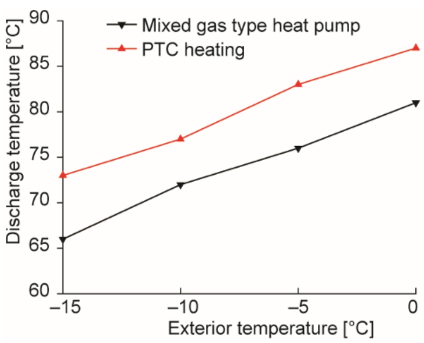

Figure 6. Changes in compressor's discharge temperature with exterior temperature changes

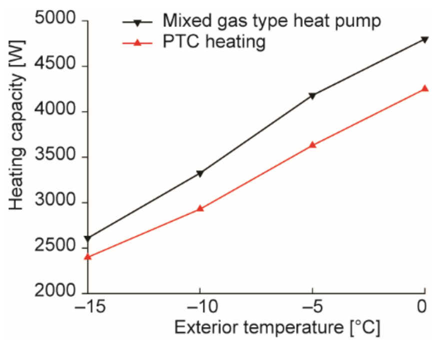

Figure 7. Changes in heat transfer volume with exterior temperature changes

According to figs 6-8, the compressor's discharge temperature, heat transfer volume, and COP of the air conditioning system with low pressure and the traditional PTC heating air conditioning system decreased with the exterior ambient temperature. Under the same exterior

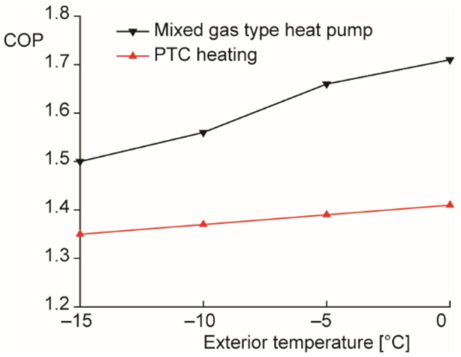

Figure 8. Changes in COP with exterior temperature changes

ambient temperature, the compressor's discharge temperature in a low pressure refrigerant gas-mixing type heat pump system was lower than that of a traditional PTC heating air conditioning system, while the heat transfer volume and COP were higher than that of the PTC heating system. As for compressor discharge temperature testing, the heat pump with a low pressure was cooler than a PTC heating system by 6 °C. As for heat transfer volume testing, the heat transfer volume of heat pump system with low pressure gas-mixing was higher than that of PTC heating system, on average, by 12.82% and as for system COP testing, the COP of the former system was higher than that of the latter. Figures 3-8 showed the thermal characteristics of the air conditioning system with low pressure make-up refrigerant gas, the results showed that different evaporator outlet superheats affected the system's heat transfer, EER, COP, compressor exhaust temperature. The optimal value of the superheater outlet value of the evaporator was obtained.

Conclusion

Thermodynamic characteristics of the working medium used in automotive air conditioners were studied, and an optimal evaporator outlet superheat value was obtained, which solved the low energy efficiency of heating and cooling air conditioners in the pure electric vehicle. A stable and reliable temperature range of –15~50 °C was achieved, and the compressor's exhaust temperature could be effectively controlled within 90 °C.

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References

[1] Deng, J., *et al.,* Development of Electric Vehicles, *Science and Technology Innovation Herald*, *28* (2011), pp. 219-220
[2] Li, H. J., *et al.*, Simulation Study on the Characteristics of Scroll Compressor with the Complement Gas of Low Pressure for Electric Vehicles Air Conditioning, *Cryo & Supercond., 42* (2014), 7, pp. 60-63
[3] Sharafian, A., *et al.,* Critical Analysis of Thermodynamic Cycle Modeling of Adsorption Cooling Systems for Light-Duty Vehicle Air Conditioning Applications, *Renewable and Sustainable Energy Rev*, *48* (2015), Aug., pp. 857-869
[4] Wasbari, F., *et al.*, A Review of Compressed-Air Hybrid Technology in Vehicle System, *Renewable and Sustainable Energy Rev*, *67* (2017), Jan., pp. 935-953
[5] Antonijevic, D., *et al.*, Heat Pump Supplemental Heating System for Motor Vehicles, *Journal of Automobile Engineering*, *218* (2004), 10, pp. 1111-1115
[6] Yokoyama, A., *et al.,* Thermal Management System for Electric Vehicles, *SAE International Journal of Materials and Manufac*, *4* (2011), June, pp. 1277-1285
[7] Steiner, A., *et al.,* Parametric Analysis of the Defrosting Process of a Reversible Heat Pump System for Electric Vehicles, *Applied Thermal Engineering*, *61* (2013), 2, pp. 393-400
[8] Li, L., *et al.*, Design and Experiment of a Heat Pump Air conditioning System for Electric Vehicles, *Journal of Refrigeration*, *34* (2013), 3, pp. 60-63

[9] Kowsky, C., *et al.,* Unitary HPAC System, *SAE International Journal of Passenger Cars-Mech*, *5* (2012), 2, pp. 1016-1025
[10] Peng, Q. H., *et al.,* Effects Analysis of Speeds on System Performance of Heat Hump Air Conditioning System for Electric Vehicle by Simulation, *Machinery Design & Manufacture* (2015), 3, pp. 35-38
[11] Yan, R. D., *et al.*, Experimental Study on the Effect of Superheat on Performance of Automotive Air conditioning, *Journal of Refrigeration*, *35* (2014), 3, pp. 86-89
[12] Qi, Z. G., Advances on Air Conditioning and Heat Pump System in Electric Vehicles – A review, *Renewable and Sustainable Energy Rev*, *38* (2014), Oct., pp. 754-764
[13] Zhou, G., *et al.*, Experimental Study on Combined Defrosting Performance of Heat Pump Air Conditioning System for Pure Electric Vehicle in Low Temperature, *Applied Thermal Engineering*, *116* (2017), Apr., pp. 677-684
[14] Li, H. J., *et al.*, Influence of Fin Thickness on Heat Transfer and Flow Performance of a Parallel Flow Evaporator, *Thermal Science, 23* (2019), 4, pp. 2413-2419
[15] Acar, B., Experimental Investigation on the Effect of Soil Type to the Ground Source Heat Pump's Performance and Energy Consumption, *Thermal Science, 24* (2020), 2A, pp. 843-852
[16] Ozener, O., Ozkan, M., Assessment of Real Driving Emissions of a Bus Operating on a Dedicated Route, *Thermal Science, 24* (2020), 1A, pp. 63-73
[17] Srinivasan, S., *et al.,* Modelling and Analysis of Automatic Air Conditioning System Using Support Vector Machine, *Thermal Science, 24* (2020), 1B, pp. 571-574

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